ALS-U
DIFFRACTION-LIMITED
LIGHT SOURCE

Progress on the Injection/ Extraction Kicker for the ALS-U

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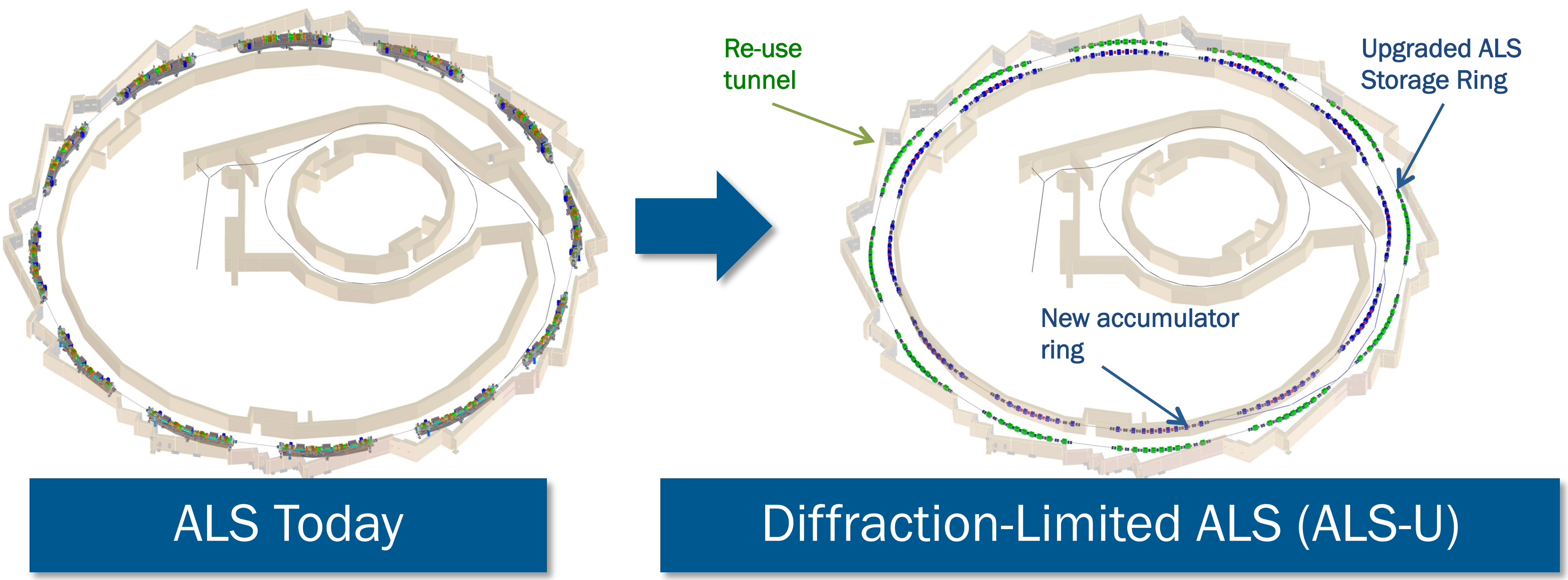
LBNL

Summary

- Introduction to the ALS-U Proposal
- On-axis Injection, Swap-out Scheme
- Injection/Extraction Kicker Requirements for the ALS-U
- Matched Striplines Kicker Design
- Pulser Design

Advanced Light Source - Upgrade



- Re-use building and tunnel infrastructure
- Upgrade injector for swap-out injection
- Upgraded ALS storage ring based on multi-bend achromat
- Potential upgrade of undulators, optics, and detectors

ALS-U Goals

Performance Goals:

1. Reduce horizontal emittance from 2000 pm to 50 pm, optimize beamsize vs. divergence
2. Preserve almost constant multibunch current at 500 mA
3. Preserve single bunch capability

Constraints:

4. Maintain existing insertion device beamlines in current state
5. Maintain existing bending magnet beamlines

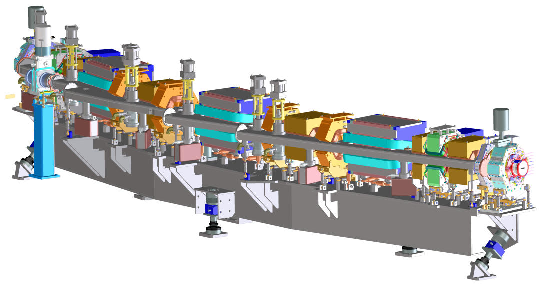
Project Execution Scope/Goals:

6. Upgrade injection system for on-axis injection
7. Reuse existing hardware when effective for cost + performance
8. Operation costs comparable to present ALS
9. Limit the downtime for installation and commissioning to one year.

ALS-U Lattice

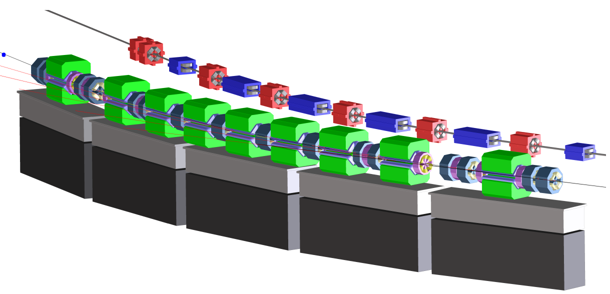
ALS today
triple-bend achromat (TBA)

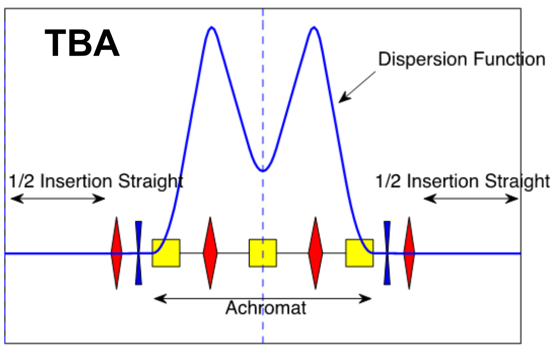
ALS-U
multi-bend achromat (9BA)



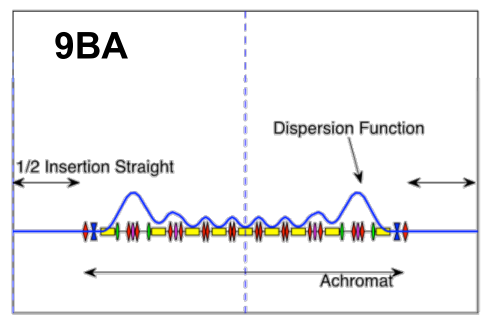
Smaller vacuum chamber…

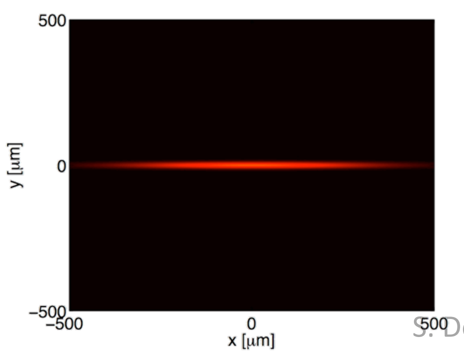
and magnets…





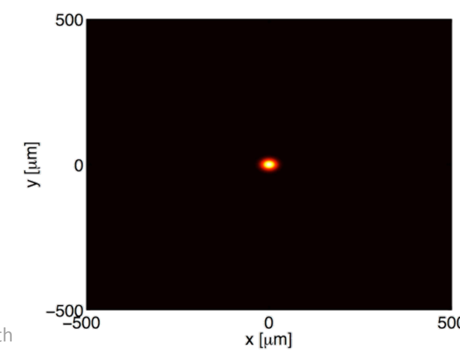
Smaller dispersion…



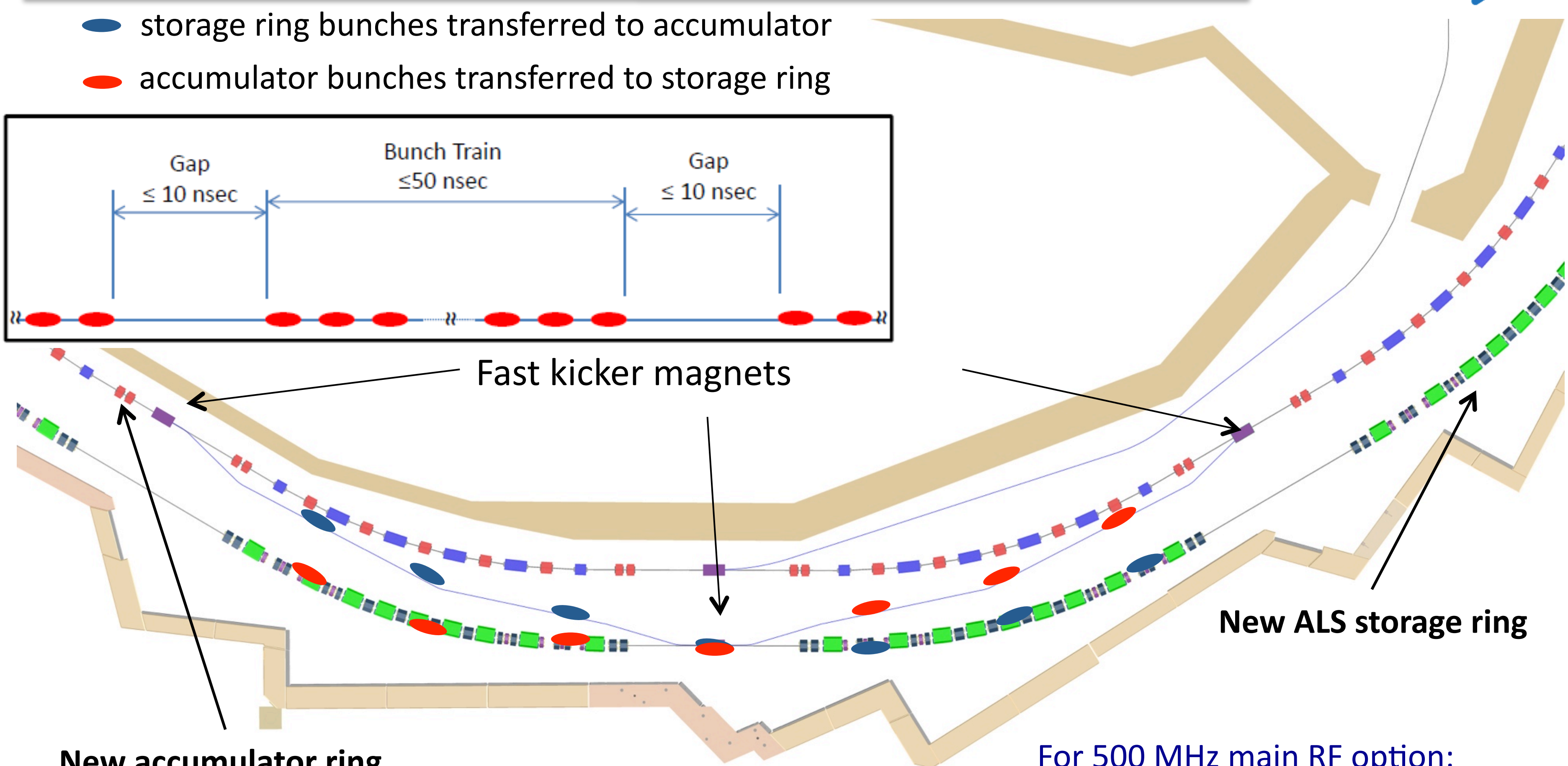


Smaller emittance…

…smaller dynamic aperture



Swap-out Injection Scheme



For 500 MHz main RF option:
11 trains of 26 bunches separated by 4-bucket gaps
For the 100 MHz option:
66 bunches with a 10 ns separation

Swap-out injection was first proposed by M. Borland for possible APS upgrades

On-axis, Swap-out Advantages

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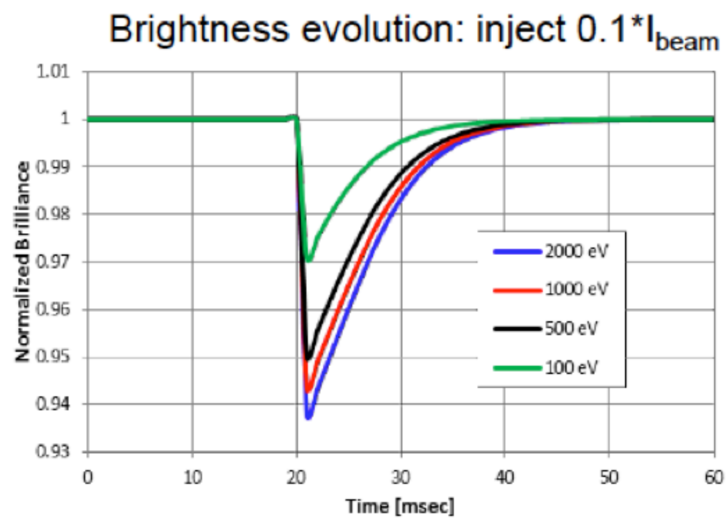
- We are forced to use such a scheme, but it also comes with advantages:

  - Minimizes injection transients.

Emittance mismatch damps in ~10 ns and its effect on brightness is of the order of a few percent

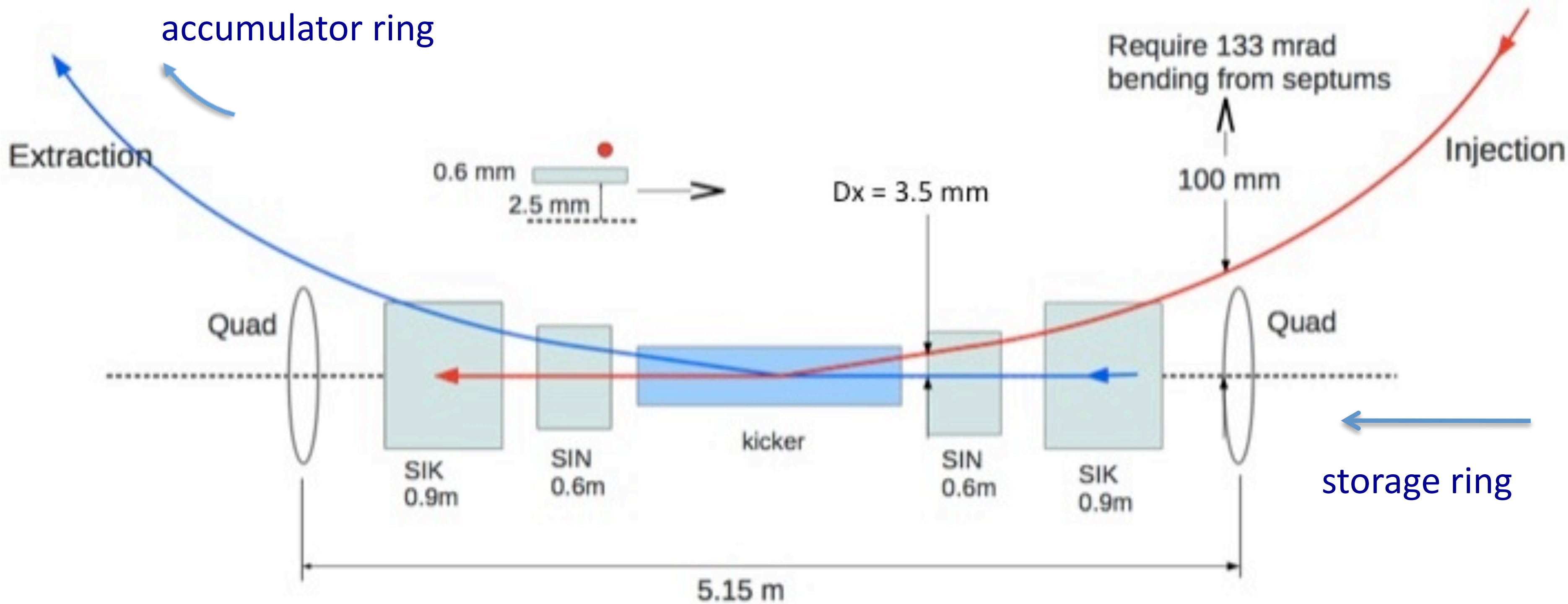


  - Minimizes current fluctuation between individual bunches for equal injection period:

$$\Delta I_b^{\max} = \frac{N_{trains} \cdot \Delta T_{inj}}{\tau_{life}}$$

In single bunch top-up N_{trains} is maximum ($N_{bunches}$) and ΔT_{inj} must be smaller. Lower limit for N_{trains} dictated by accumulator/booster considerations.

Kicker Requirements



Beam Energy: 2 GeV
Bend Angle: 3.5 mrad
Total Kicker Length: 2 m

Rise/Fall Time: ≤ 10 ns
Max. Pulse Length: 50 ns
Repetition Rate: ≈ 30 s

Beam Stay Clear: 2.5 mm

Stripline Kicker Design

• We developed a kicker design based on tapered striplines (kicker can only slow down the pulser)

• In its active mode the kicker acts as a transformer between the pulser voltage and the deflecting field. Working range is relatively narrow band and low frequency (50 ps long pulse, with sub-10 ns rise/fall time spectrum is contained within 100 MHz. (odd mode, shunt impedance, LF impedance matching, residual fields, fringe fields)

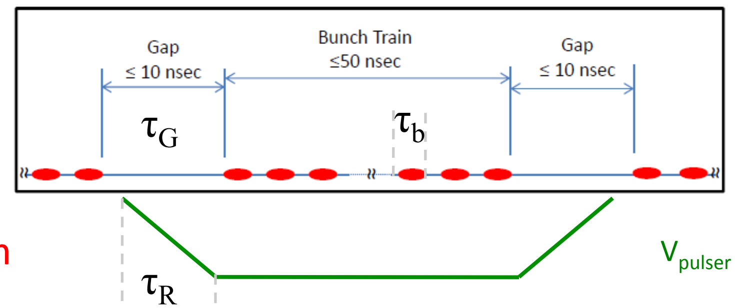
• In its passive mode the kicker acts as a pickup of the beam wakefield, which is wide-band and high frequency since the bunch spectrum extends above 10 GHz. (even mode, beam coupling impedance)

• Ideally, the kicker deflects the beam as desired while all its other effects on the beam, in either active or passive mode, are negligible. For the analysis we used analytical models and 3D simulations (CST Studio Suite).

Shunt Impedance

$$L_{\mathrm{mod}} \le \frac{\overset{6\ \mathrm{ns}}{\tau_G} - \tau_R - \overset{0.4\ \mathrm{ns}}{\tau_b}}{2} c$$

maximum length of a stripline module: 50 cm



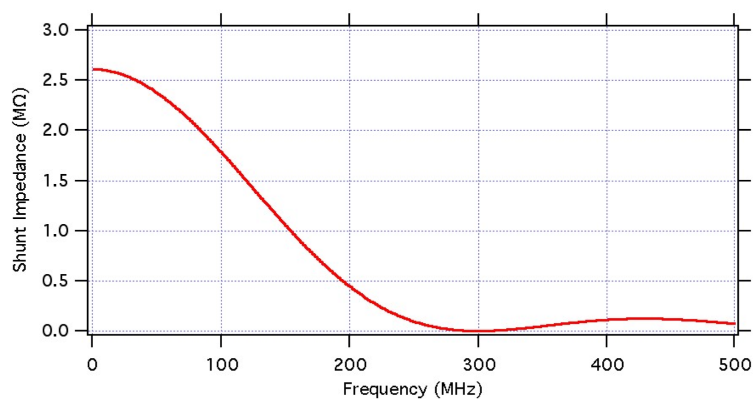
$$\pm V_0 = \frac{\Theta E_b \overset{6\ \mathrm{mm}}{h}}{4L_{tot}} = 5.25\ \mathrm{kV}$$

Stripline voltage for 3.5 mrad deflection over 2 meters (4 modules)

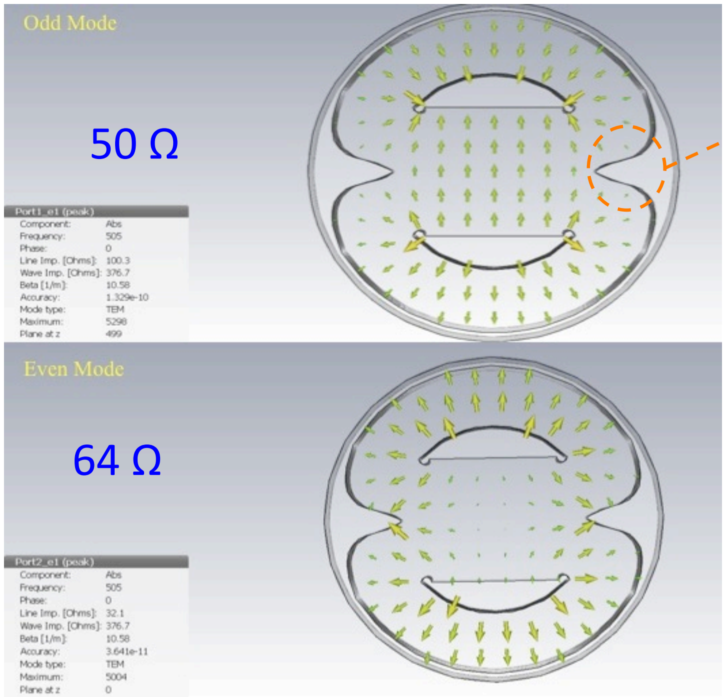
$$Z_s(\omega) = \frac{(V_\perp / N_{\mathrm{mod}})^2}{2P_{\mathrm{mod}}} =$$

$$= 2Z_0 \left(\frac{L_{\mathrm{mod}}\, g_\perp}{h/2} \right)^2 \left(\frac{\sin(\omega L_{\mathrm{mod}} / c)}{\omega L_{\mathrm{mod}} / c} \right)^2$$

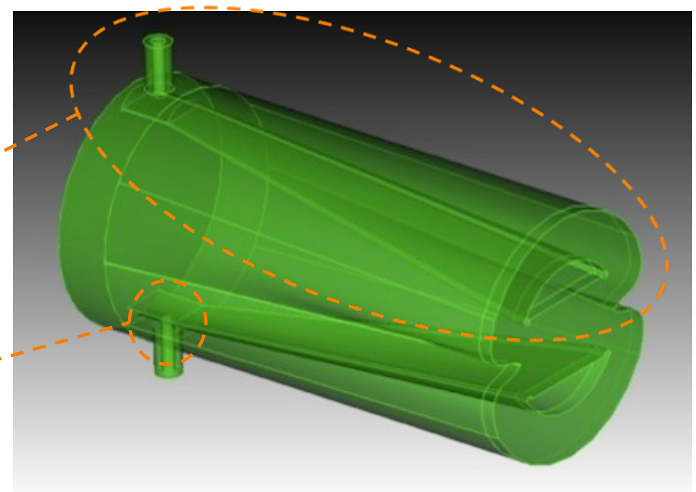
Shunt impedance



Physical Implementation



Transverse plane fenders, to lower the even mode characteristic impedance from 77 to 64 Ω



Longitudinal tapers to reduce beam coupling impedance at high frequency and improve the feedthrough-to-stripline 50 Ω matching

Beam Coupling Impedance

$$Z_{//}^{\mathrm{Re}}(\omega) = Z_{even} g_{//}^2 \sin^2(\omega L_{\mathrm{mod}} / c)$$

$$Z_{//}^{\mathrm{Im}}(\omega) = \frac{1}{2} Z_{even} g_{//}^2 \sin(2\omega L_{\mathrm{mod}} / c)$$

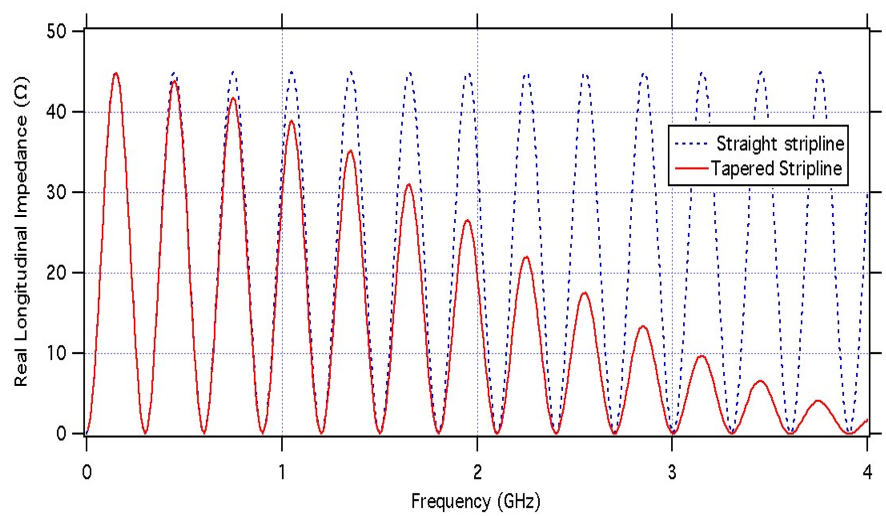
$$Z_{\perp} = Z_{//} \frac{g_{\perp}^2 Z_{odd}}{g_{//}^2 Z_{even}} \frac{c}{\omega (h/2)^2}$$

$$\times \quad \frac{Sin^2(\omega \ell / c)}{(\omega \ell / c)^2}$$

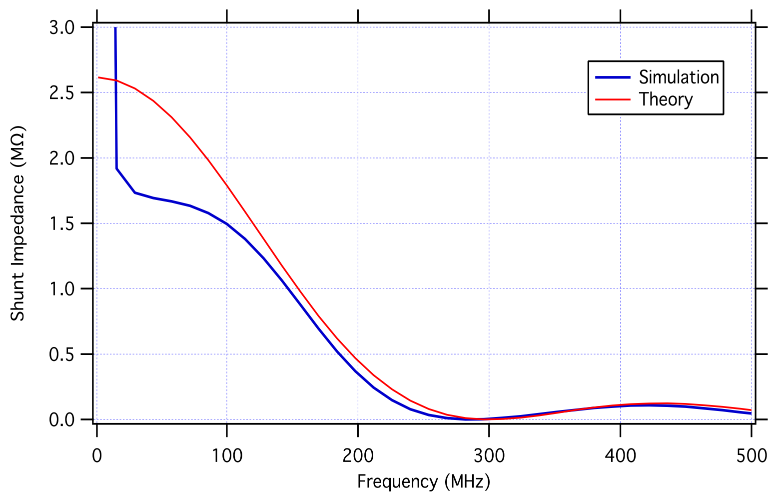
Tapering factor

Longitudinal and transverse impedance (untapered)

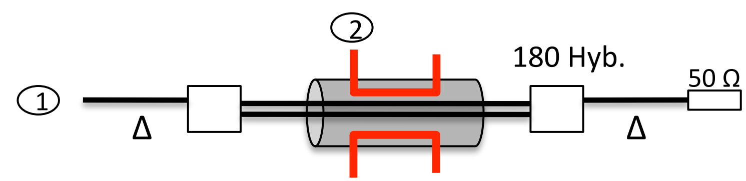
$=$



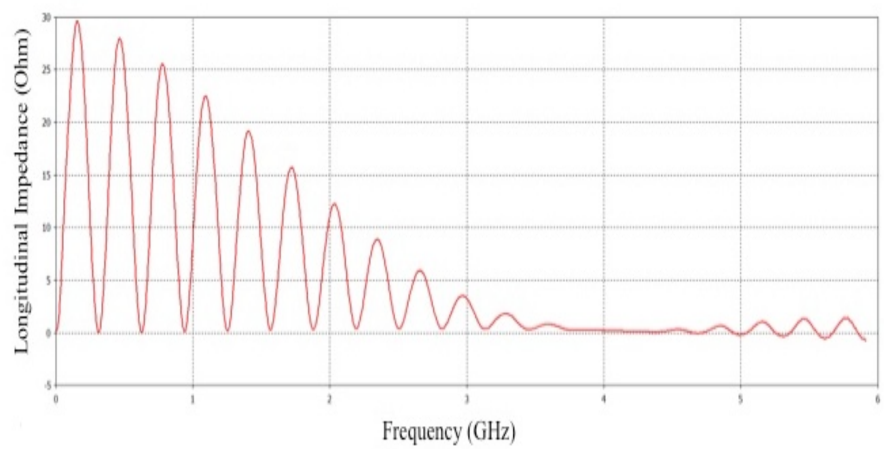
3D Simulations



Shunt impedance calculated on the 3D model using the 2-wire method. <u>This takes into account tapers and fringe fields.</u>



Longitudinal impedance derived by the simulated wakefield of a gaussian bunch transit through the kicker



Residual Fields

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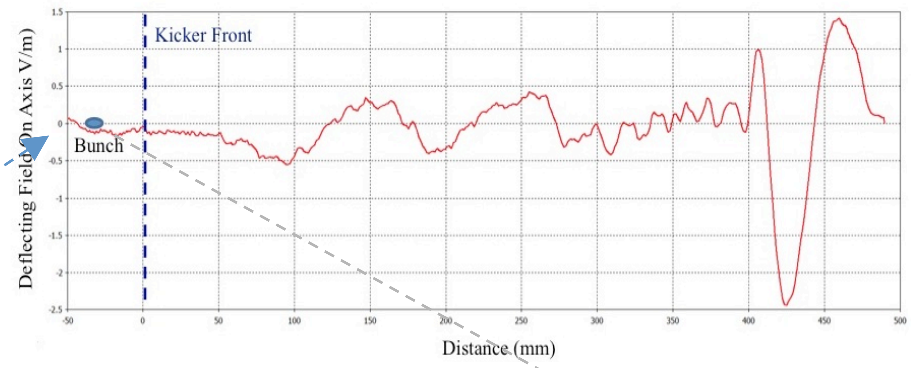
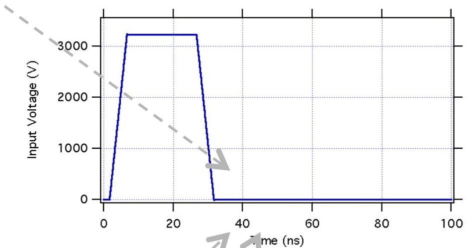
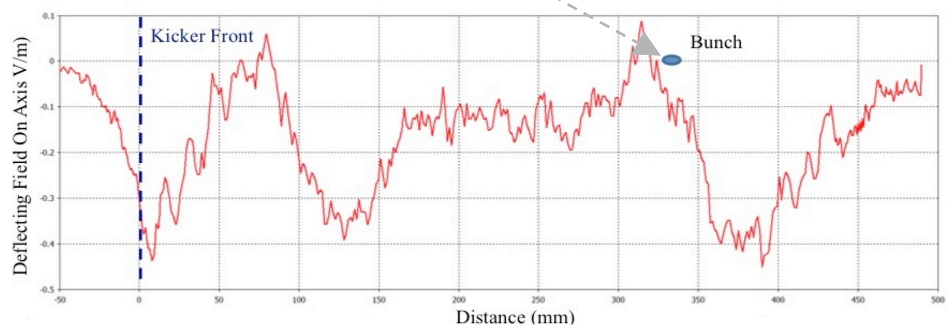


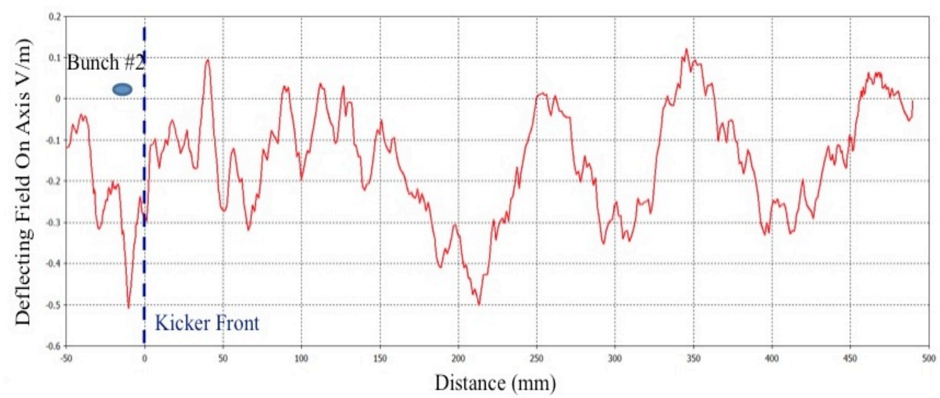
input pulse



trailing bunch

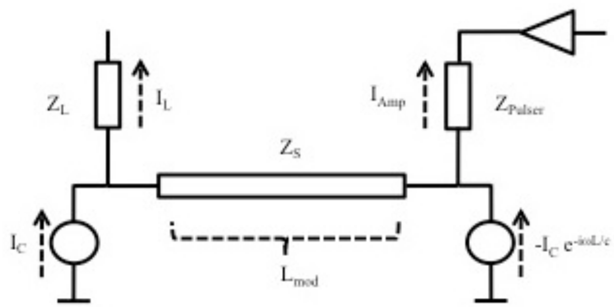
Fields values normalized to 1 W input power per feedthrough (1/2000 of the actual applied voltage)



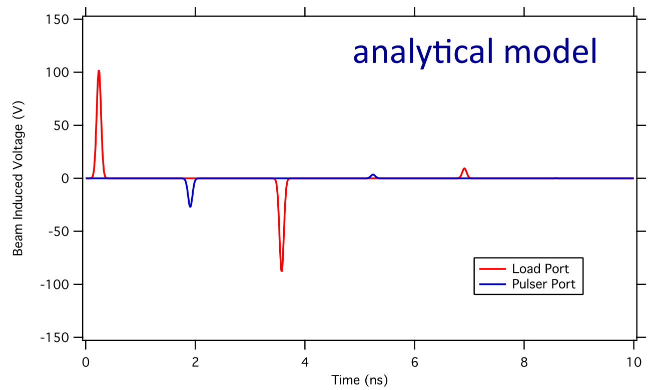


We have also verified that the kicking field uniformity is acceptable and fringe fields effects on beam dynamics are being evaluated .

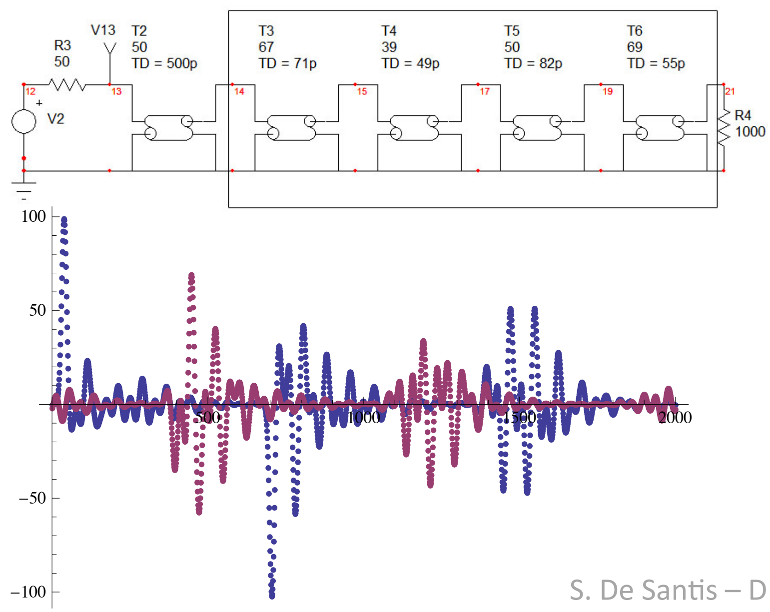
Beam Induced Voltage

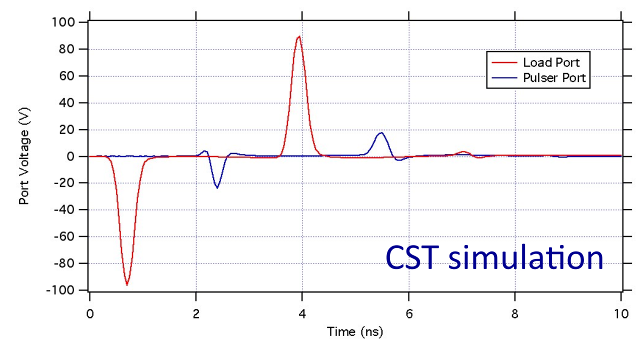


Stripline excited by the beam (even mode) is mismatched. This causes beam signals to be induced in the pulser port and to bounce back and forth



High-frequency feedthrough model based on TDR measurements



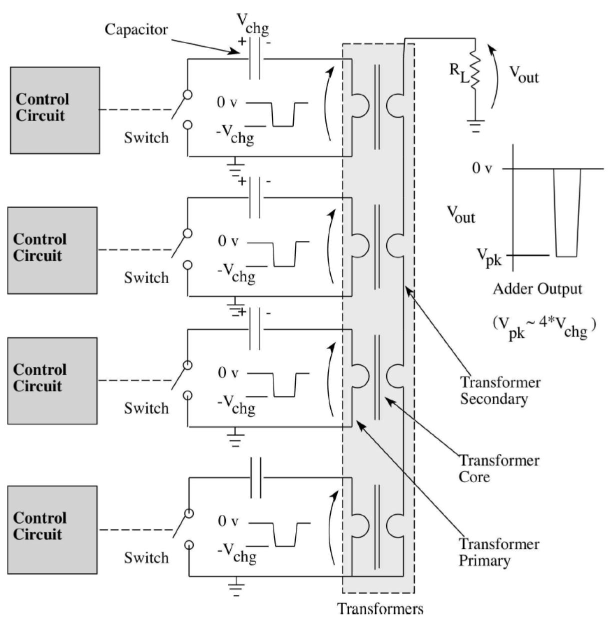


Ideal, purely resistive, load

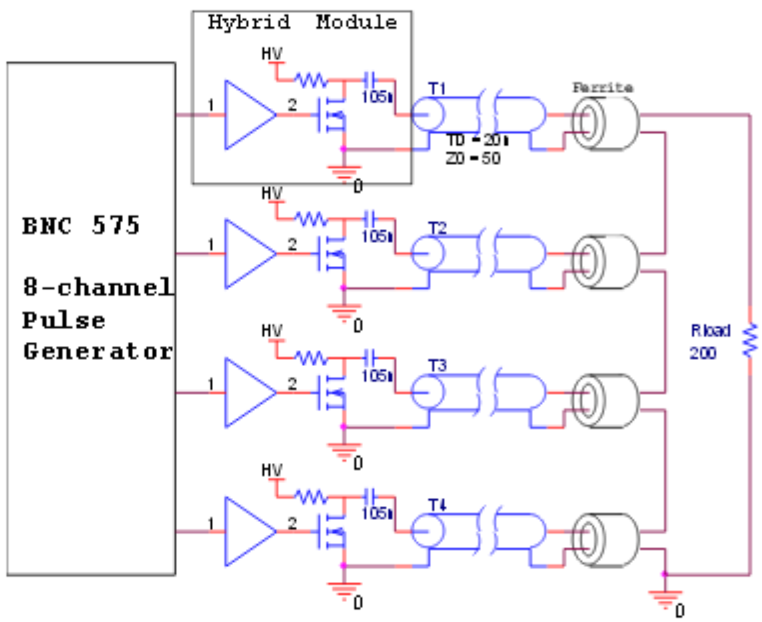
Pulser Design

Considered architectures:

- MOSFET switched inductive adder – being pursued
- MOSFET switched transmission line adder – being pursued
- Thyratron switched coaxial line – high di/dt, obsolete technology
- MOSFET (array) switched capacitor – array reliability and maintenance question (Behlke, etc.), requires low inductance architecture



INDUCTIVE ADDER



TRANSMISSION LINE ADDER

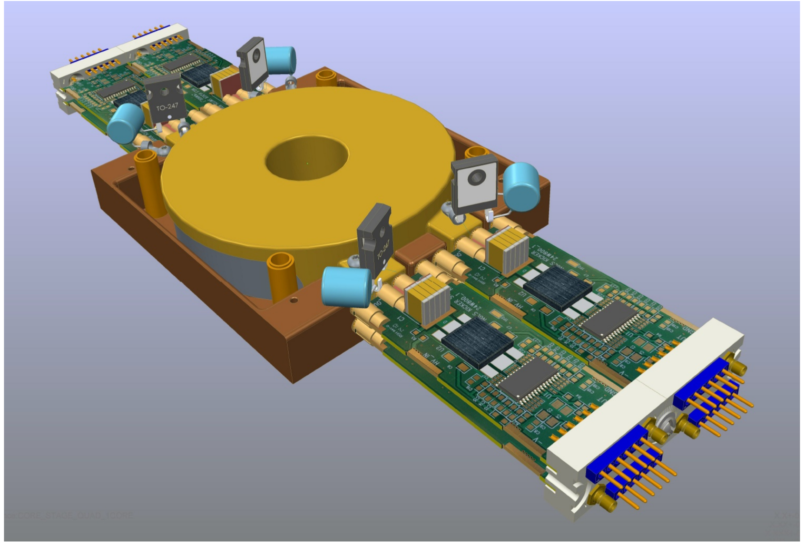
Inductive Adder – main effort to date

- Advantages
  - Individual stages operate at a fraction of the total output voltage
  - Each stage is referenced to ground
  - High step-up ratio with negligible leakage inductance
  - Can configure for simultaneously generating identical pulses of opposite polarity
- Disadvantages
  - Many parts ($$)
  - Complicated packaging ($$)

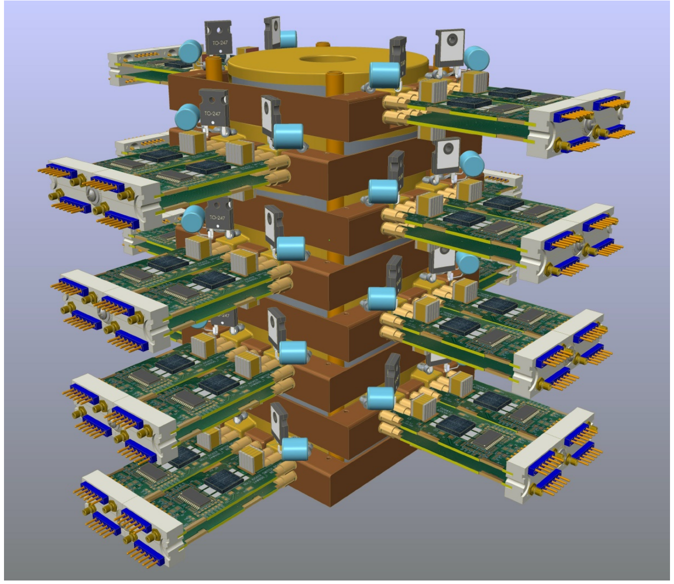
- **+/- 5.25kV on 2 parallel 50 ohm coaxial cables (5.25kV / 25ohms = 210A)**
- **8 parallel boards per stage (210A / 8 = 26.3A per MOSFET)**
- **8 stages (660V / stage) – charge to ~760V on a 1kV rated device**
- **Core: CMD5005 NiZn ferrite**
- **MOSFET and gate driver: DEI**
- **Output connectors: none, custom cable termination within the adder structure**
- **Output cable: RG-213 (arbitrary)**
- **Input connector/feedthrough to kicker: needs to be identified**

Inductive Adder – Prototype

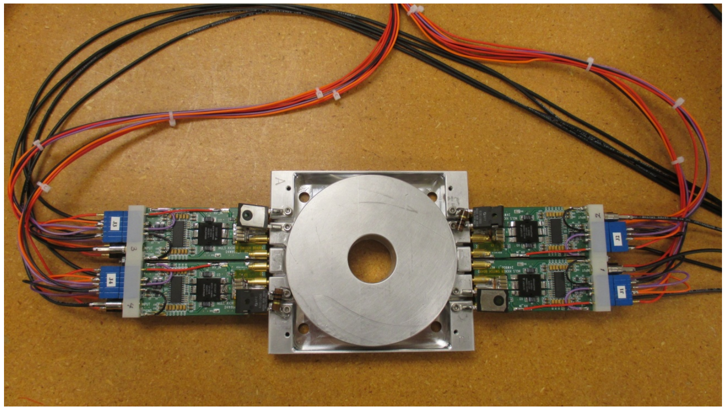
SINGLE STAGE



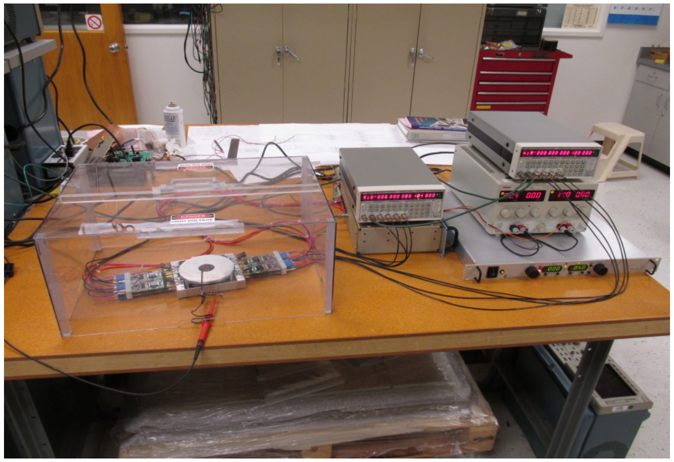
8-STAGE FULL MODULE



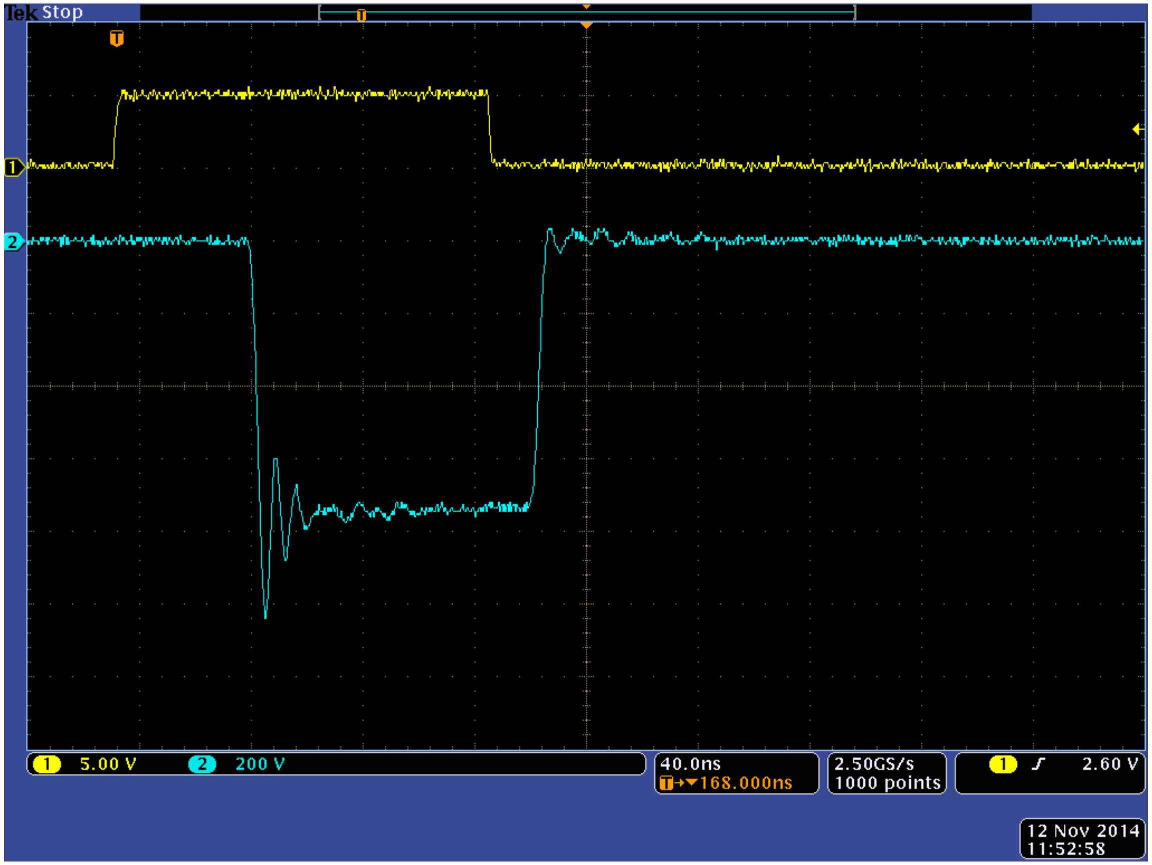
"REAL" SINGLE STAGE...



...BEING TESTED

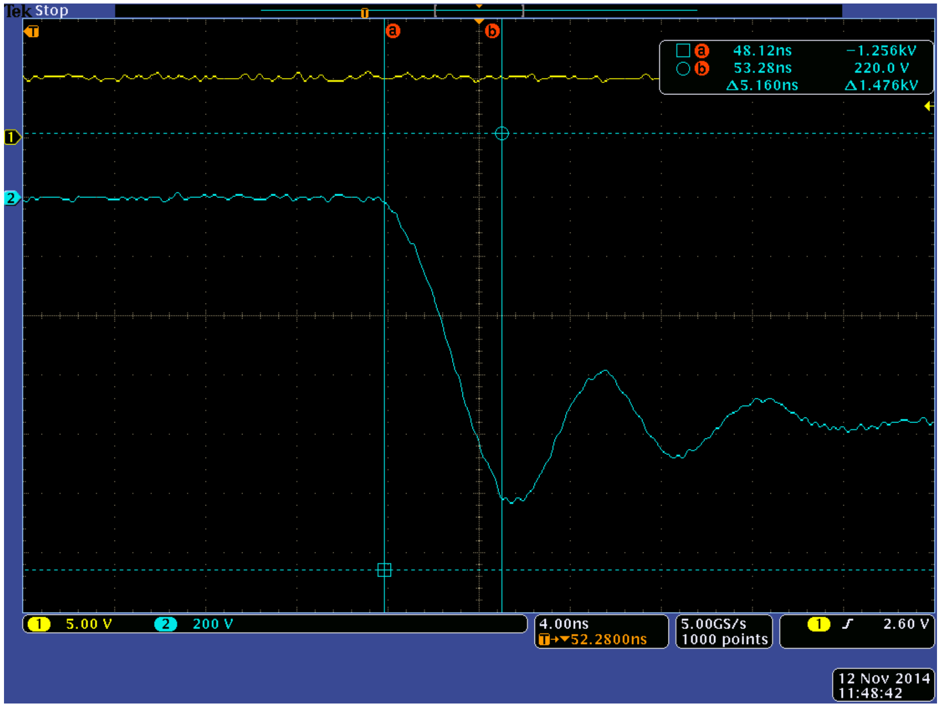


Inductive Adder – Tests

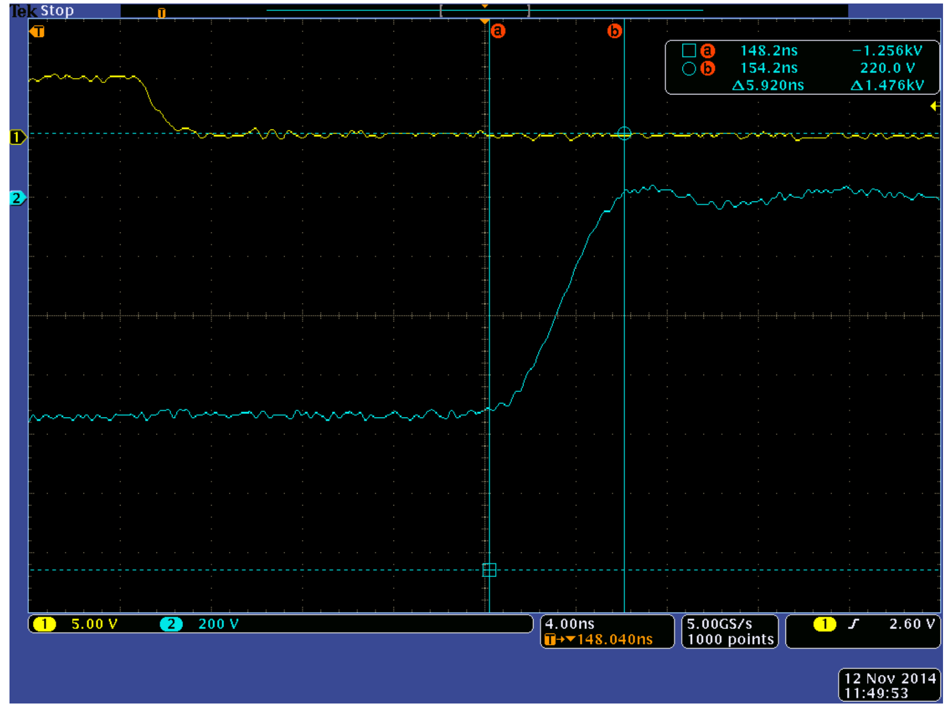


FWHM pulsewidth = 100 ns
Flat top voltage = 740V

Inductive Adder – Rise/Fall Time



0-100% rise ~ 5.2 ns

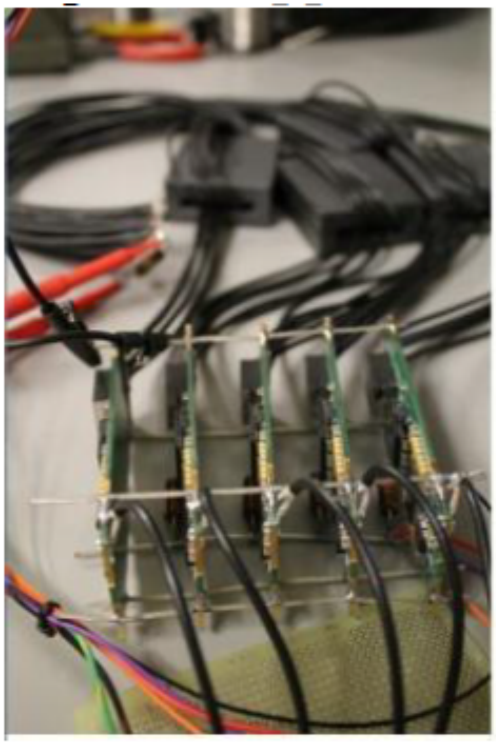


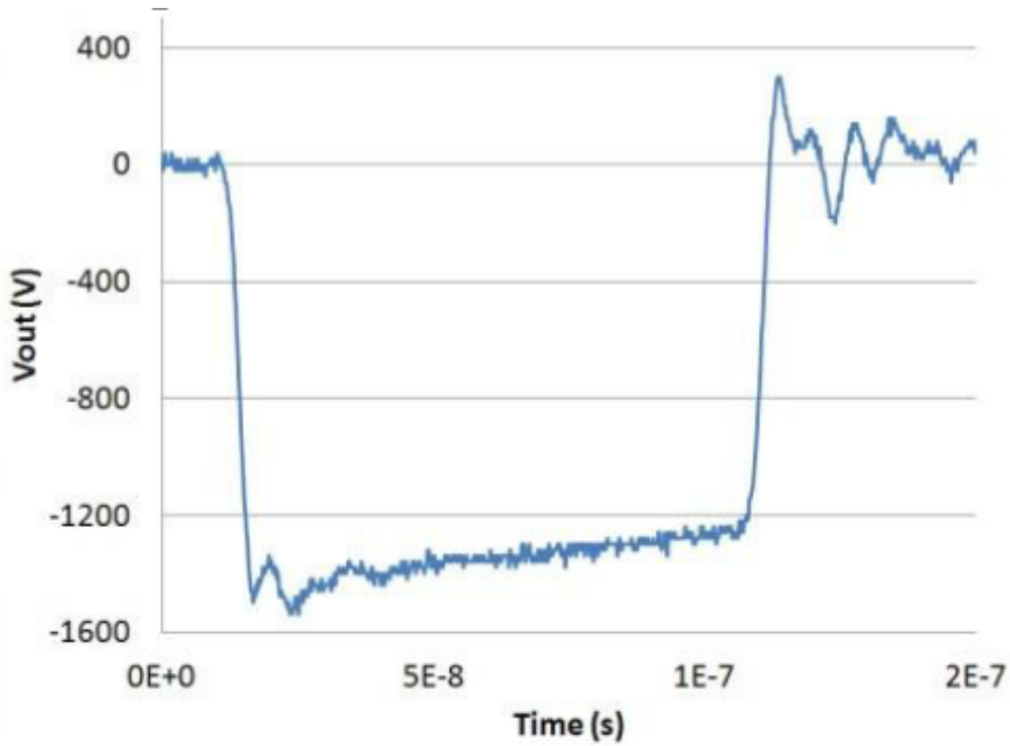
0-100% fall ~ 5.9 ns

Voltage overshoot and ringing needs to be understood and reduced

- Clamping diode capacitance ?
- HV probe ?
- Core housing capacitance ?
- PC board details ?

Transmission Line Adder





Very low impedance transmission lines could present a packaging problem

Conclusions

- Injection/Extraction kicker is a critical component for the ALS upgrade.
- Design of a stripline kicker is well underway and it seems to satisfy requirements.
- Pulsers technologies are being evaluated, with efforts directed towards inductive adder at present.
- Future steps include a full scale test of the inductive adder and a more thorough evaluation of the kicker effects on beam dynamics.